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On October 28, 1934, with appropriate ceremony, the first delivery of water from the Tuolumne River into Crystal Springs Reservoir in San Mateo County took place. This marked the completion of the initial development of San Francisco's Hetch Hetchy Water Supply Project, an enterprise representing an investment in excess of $100,000,000, and on which actual construction work had been carried on for a period of over twenty years. The Project is a monument to the engineering genius and indomitable courage of M. M. O'Shaughnessy, who, as Chief Engineer and later as Consulting Engineer, was the directing force through all those years. He did not live to witness the final consummation of his work, death cutting him off on October 12, 1934, scarcely two weeks before the dedication ceremonies.

It is the purpose of this paper to review the considerations which led to the choice of the Hetch Hetchy Project, for San Francisco's future water supply, to describe briefly the project, and to discuss, generally, the benefits which have accrued, or may reasonably be expected to accrue, from the development and use of this water supply.

CONSIDERATIONS DETERMINING SELECTION OF HETCH HETCHY

San Francisco since its earliest days had been dependent upon private enterprise for its water supply. Prior to the creation of the California State Railroad Commission, with jurisdiction over the operations of all privately-owned public utilities, the rate-fixing power for water used in San Francisco lay in the hands of the local Board of Supervisors, and resulted in the existence of a constant state of political hostility against the private company. Failure of the company to extend its service to meet the needs of the constantly expanding residential developments and occasional recurring dry periods with threatened shortage of the water supply led to spasmodic action by succeeding governing officials and boards of supervisors, requiring investigations and reports to be made of various sources of water supply which might be acquired and developed for a municipally-owned system. It was not, however, until the adoption of its charter of 1900 that a definite movement was inaugurated which finally led to the acquisition and construction of the Hetch Hetchy Project. This charter declared for the gradual acquisition and ultimate ownership of all public utilities and prescribed that—"In securing estimates of the original cost of construction and completion of water works by the City and County, the supervisors must procure and place on file plans and estimates of the cost of obtaining from all of the several available sources a sufficient and permanent supply of good pure water."

In response to this mandate, C. E. Grunsky, then City Engineer and a man of splendid ability, made an exhaustive study of the whole water supply question, investigating some fourteen possible available sources of supply. On the basis of his studies he recommended that the Tuolumne River be selected as the source of San Francisco's future supply, as presenting "the following unrivalled advantages:

> "*First:* Absolute purity by reason of the uninhabitable character of the entire watershed tributary to the reservoirs and largely within a forest reservation.
>
> "*Second:* Abundance far beyond possible future demands for all purposes.
>
> "*Third:* Largest and most numerous sites for storage.
>
> "*Fourth:* Freedom from complicating water rights.
>
> "*Fifth:* Power possibilities outside the reservation."

He added:

> "It has the drawbacks of distance to overcome, requiring the construction of conduits aggregating 142 miles in length. But considering the partial pollution and the rapid rate of pollution to which all other sources may in the future be subjected, particularly nearby sources, the Tuolumne River is far superior to any other."

In setting up a basis of comparison for the several possible sources which were under consideration, Mr. Grunsky stated:

> "The availability of a source of water supply . . . is determined by the quality of water delivered, its quantity, the reliability of service and cost."
>
> "The first requisite beyond question is quality . . . if within reach at a reasonable cost, the water of unquestioned purity should be preferred and is

> considered to be more available than a water obtainable at less expense, but the use of which might under untoward circumstances give rise to some calamity."
>
> "The water supply must be an unfailing one, not alone by reason of its abundance at its source, but also by reason of the safety of the works for its delivery. . . .
>
> "In making the financial comparison, due regard should be had to the cost of operation, maintenance and repairs."

In summing up, Mr. Grunsky placed the Tuolumne River project, of all sources studied, highest in quality and quantity of water, and the Spring Valley System to the extent of its capacity, as first in reliability of service.

It may be pointed out at this time that acquisition of the Spring Valley System by the City, with its large storage reservoirs located close into San Francisco, and the operation of these two systems in conjunction with each other, has served to strengthen the feature of reliability beyond the standard afforded by either system individually.

On the basis of Mr. Grunsky's studies and report San Francisco committed itself to this project, but before construction was under way San Francisco was called upon by a new Secretary of Interior, Mr. Ballinger, to show cause as to why the permit for developing the project on Federal lands granted by Secretary of Interior Garfield should not be revoked with reference to the development of the Hetch Hetchy Reservoir, further exhaustive studies were again required to be made of all available sources of supply and these in turn were subjected to analysis and review by a board of Army Engineers appointed by the President. In the meantime, the plan for the development of the Hetch Hetchy had been modified on the basis of a report and recommendation of John R. Freeman, who had been retained by the City, and all other projects were considered by the Army Board on a basis of comparable development.

In its report, in considering the question as to the availability of a source of the supply, the Army Board set up the following conditions to be met:

> "*First:* The water yield shall be sufficient under the most severe conditions of runoff to meet the requirements of the Communities and of good potable quality.
>
> "*Second:* The water can be collected and delivered with reasonable economy.
>
> "*Third:* No injury shall be caused, without proper compensation, to any industries or lands that have a just claim upon the water."

The Board confirmed the selection of the Hetch Hetchy Project as the most available source and in its conclusions found:

> "The project proposed by the City of San Francisco known as the Hetch Hetchy Project is about $20,000,000 cheaper than any other feasible project for furnishing an adequate supply. . . .
>
> "The Hetch Hetchy Project has the additional advantage of permitting the development of a greater amount of power than any other."

The Board at this time estimated a power development of 115,000 horsepower which it capitalized at $45,000,000.

DESCRIPTION OF PROJECT

Before proceeding to discuss the main subject it is perhaps desirable to present, briefly, a general description of the project with some attention to those features affecting the quantity and quality of the water and certain other aspects of the system.

The water supply of the Hetch Hetchy Project is derived from some 652 square miles of watershed of the upper reaches of the Tuolumne River, of which area 459 square miles drain into the Hetch Hetchy Reservoir created by the construction of the O'Shaughnessy Dam, 79 square miles are directly tributary to Lake Eleanor and which in the future will be supplemented by the diversion of the drainage from some 114 square miles of Cherry Creek. Approximately 92 per cent of the watershed lies above elevation 6000 in rugged granite mountains and is uninhabitable except for about three months in summer. The entire area tributary to the Hetch Hetchy Reservoir and Lake Eleanor lies within the boundaries of the Yosemite National Park while the Cherry Creek drainage lies in the Stanislaus National Forest. In referring to this watershed in his report Mr. Allen Hazen stated—"It would be difficult to conceive of a more perfect gathering ground or one better adopted to produce water of greater purity. The water will be almost ideally safe."

The average yield of the Tuolumne measured above La Grange where the first major irrigation diversions are made is about two million acre feet annually.

Careful estimate of the safe yield available for San Francisco with the immediate storage development of 388,000 acre feet is 210 million gallons daily. The ultimate yield of the Hetch Hetchy Project available for water supply for the San Francisco Bay area is estimated at 400 m.g.d. on the basis of a total storage development of 1,100,000 acre feet.

The principal impounding reservoir at present developed is in the Hetch Hetchy Valley, created by the construction of the O'Shaughnessy Dam. This dam, originally creating storage capacity of 206,000 acre feet is at present time being raised some 85 feet to develop storage at this site to its ultimate capacity of 360,000 acre feet. A second reservoir at Lake Eleanor provides present storage capacity of 28,000 acre feet. Eleanor Reservoir, built primarily in connection with the operation of a small power plant at Early Intake for construction purposes, serves also as a measure of water right protection. Future plans provide for ultimate development of 218,000 acre feet storage at this site.

Water released from the Hetch Hetchy Reservoir, at present flows down the Tuolumne Canyon, approximately 12 miles, to a diversion dam (crest elevation 2356) and headworks at Early Intake, where it enters what is known as the Mountain Division tunnel 19 miles in length leading from Early Intake to Priest Regulating Reservoir.

Water released from Lake Eleanor flows about 8 miles in Eleanor Creek and Cherry River where by means of a small dam it is diverted into the Lower Cherry Aqueduct, approximately 3¼ miles in length with capacity of 200 cubic feet per second and consisting of a series of tunnels with intervening sections of concrete-lined canal, flumes and pipe. From the lower end of this canal, water is dropped through a penstock to operate the Early Intake power plant of 3000 KV-A capacity, originally built for construction purposes but since continued in commercial operation. Water discharged from this plant, except in flood periods when it is wasted back to the river, is delivered through a 60-inch steel pipe into the Mountain Aqueduct at a point about ½ mile below Early Intake. Water from the canal not required for power purposes is discharged above the Early Intake Diversion, through a connecting steel pipe.

For the upper eight miles, the Mountain tunnel is through solid granite and is unlined save for a few short sections. The flow section in this unlined tunnel is, approximately, 168 square feet. The lower 11 miles of this tunnel are concrete-lined throughout, it is of horseshoe section, 10 feet 3 inches in diameter and flow section of, approximately, 88 square feet.

Priest Reservoir at the lower end of the Mountain Aqueduct serves as a regulating reservoir, or forebay for the Moccasin power plant below. This reservoir created by the construction of an earth fill dam across a small ravine has a capacity of 2350 acre feet with water surface elevation at 2240. Surface drainage may flow into the reservoir from limited area largely owned by City and which is fenced, though should it be found necessary at any time this surface flow, can at small expense, be intercepted by a drain ditch.

From Priest Reservoir the water flows through approximately a mile of concrete-lined tunnel, of horseshoe shape, 13 feet in diameter to a concrete surge chamber from where it enters the steel penstocks leading to the Moccasin power plant.

The Moccasin power plant, operating under a head of 1316 feet, with installed capacity of 80,000 KV-A will deliver a 24-hour average output of 60,000 KV-A at 75 per cent load factor. Plans provide for the installation of two additional units to provide for maintaining the same output at 50 per cent load factor.

The discharge from the water wheels passes into the Moccasin regulating reservoir of some 500 acre-feet capacity, formed by constructing a small earth dam across Moccasin Creek just below the power house. Moccasin Creek above the reservoir has a watershed of, approximately, 20 square miles subject to flood flows of several thousand cubic feet per second. Drainage from the entire area will be intercepted by a small diversion dam immediately above the reservoir and by-passed through the reservoir in a concrete conduit, at present under construction. Pending completion of these works it has been necessary, at times of heavy flood flow, to cut off delivery of the water on account of the high turbidity.

From the Moccasin Reservoir to the Crystal Springs Reservoir the water flows 116 miles in a closed conduit, 46.2 miles of which is concrete-lined tunnel and 69.8 miles of pie. The Foot-hill Division tunnel, of horseshoe section 10 feet 3 inches in diameter extends from Moccasin 15.8 miles westerly to the edge of the San Joaquin Valley. The tunnel is broken 5½ miles from Moccasin by the Tuolumne Canyon which is crossed at Red Mountain Bar by a submerged concrete-lined and jacketed steel siphon 9½ feet in diameter and ½ mile in length. Here provision is made for the installation of a power plant of 30,000 HP capacity to utilize the water not required in the early years for San Francisco. From Early Intake to the west portal to the Foothill Tunnel the aqueduct has a capacity of 400 million gallons daily. The San Joaquin Valley is crossed by a steel pipe of 60-inch equivalent diameter, 47½ miles in length, with capacity of 70 m.g.d. At the west edge of the Valley at Tesla Portal, connection is made with the Coast Range Tunnel extending 29.1 miles to Irvington

Portal on the west slope. This tunnel is broken at Alameda Creek which is crossed by a 69-inch diameter steel cylinder reinforced concrete pipe siphon a little over 3,000 feet in length. This tunnel is concrete lined of circular section 10 feet 3 inches in diameter, but due to flatter grade than the upper tunnel the capacity is reduced to 250 m.g.d.

At Irvington Portal is installed a chlorinating and ammoniating plant equipped with five 300-pound vacuum type, solution feed chlorinating machine and one 200-pound solution feed ammoniating machine.

From Irvington Portal to the east portal of Pulgas Tunnel two lines of pipe, of 60-inch and 66-inch nominal diameter, extend approximately 21.3 miles, except for the submarine crossings at Newark Slough and San Francisco Bay which are made with 42-inch cast iron flexible joint pipe in the original line and with 54-inch concrete jacketed steel flanged pipe in the line recently completed. Pulgas Tunnel, $1\frac{3}{4}$ miles in length, is similar to the Mountain Tunnels, and concrete lined throughout extends to Crystal Springs Reservoir.

The Pulgas outfall where the water from the Hetch Hetchy Aqueduct discharges into Crystal Springs Reservoir at elevation 287 marks the present terminus of the Hetch Hetchy Project, from this point on the old Spring Valley System is used for transmission and distribution of the water.

Under the Raker Act, San Francisco is required to utilize her existing sources of supply as far as available before drawing upon the Tuolumne source, so in Crystal Springs Reservoir Hetch Hetchy water mingles with that collected from the tributary watersheds and other local sources.

Water released from the Calaveras Reservoir of the old Spring Valley System, located in Alameda and Santa Clara Counties, may be discharged through a connecting pipe line by gravity directly into the Hetch Hetchy Aqueduct at the Alameda siphon, a short length of steel pipe connecting two sections of Coast Range tunnel south of Sunol. Calaveras Reservoir with a capacity of 32.8 billion gallons impounds the runoff from, approximately, 135 miles (square miles) of watershed in Alameda and San Mateo Counties. An aerator plant and a chlorinating plant immediately below the dam serves to aerate and sterilize the water released from the reservoir before it enters the connecting pipe line leading to the Hetch Hetchy Aqueduct.

DISCUSSION OF BENEFITS ACCRUING

San Francisco has invested over $100,000,000 in the Hetch Hetchy Project, in addition to the $41,000,000 paid for the acquisition of the Spring Valley, to secure an ideally pure source of water supply, perpetually protected against any serious pollution, abundant not only for its own but for the needs of the dependent area of the entire Peninsula for all time. The necessary dams, aqueducts and appurtenant water works and electric power plants are of sound engineering design and first class construction, econimically built to deliver the water from this source by gravity to Crystal Springs Reservoir from which point it is now being delivered through the old Spring Valley System to San Francisco.

These are the physical assets. In what manner and to what extent do the people of San Francisco and other communities benefit thereby? This is rather a broad subject and will be discussed in general terms under several heads.

1. Improved sanitary and physical characteristics

Water as impounded in the Hetch Hetchy Reservoir is of the highest sanitary standard, unfortunately it can not be delivered to the ultimate consumer in its original purity and quality. In its transmission to San Francisco it is exposed to possible contamination from surface drainage at serveral points: namely, the channel of the Tuolumne River wherein water released from O'Shaughnessy Dam flows for some 12 miles to Early Intake, Priest Reservoir, Moccasin Reservoir, and in the Coast Range Tunnels, due to seepage of highly mineralized ground water. As water from Hetch Hetchy is discharged into Crystal Springs Reservoir for delivery to San Francisco, it tends to assume the sanitary and physical characteristics of the local waters stored therein. As mentioned, under the terms of the Raker Act water from local sources must be used to the available capacity of those sources before diverting water from Hetch Hetchy.

It is desirable from an operating point of view to deliver to consumers as nearly as possible water of uniform quality, which is accomplished by the mixing of the waters in this large reservoir. Crystal Springs and the other Peninsula reservoirs have a combined capacity of 29.5 billion gallons, with watershed area of about 36 square miles all of which, with very minor exception, is owned by the Department and is fenced and patrolled. The clean, naturally wooded, and protected watershed, and the long period of storage, contribute to produce a raw water of excellent sanitary quality—in fact, during the 75 years of its history there has not been a single death due to a water-borne disease traceable to the water supply. As a result of the several factors tending to equalize the sanitary qualities of the Hetch Hetchy and local waters, and the excellent quality of the local supply, little improvement in sanitary quality was to be expected.

The water has not been in use for a sufficient period for our Department of Public Health to note any effect upon the public health statistics.

Apparently, certain direct benefits accrue as affecting the amount of chemicals used in the treatment of the supply, and while it may be somewhat premature to determine at this time the extent of such benefit, mention may be made of the fact. Our records indicate that the algae growth in the Crystal Springs Reservoirs during the year 1935 was but 60 per cent of that occurring in 1934, but three copper sulphate treatments were required in 1935 as against seven in 1934. Records so far for the year 1936 indicate conditions similar to 1935. The Hetch Hetchy water has a tendency to slightly reduce the temperature of the water in the reservoir, the yearly mean temperature for the year 1935 being 60.3 as against 61.4 for the preceding year. There are several factors which affect algae growth; cooler water and reduction of the amount of mineral and organic matter in the water all tend to reduce the growth, while on the other hand reduced turbidity in the lake permits greater penetration of the sunlight and tends to stimulate algae growths.

During the past year, due to the smaller amount of organic matter present, it has been possible to reduce the chlorine dosage at the reservoir outlet from an average of 4–5 to 3 pounds per million.

In recent years, due to increasing consumption and seasons of deficient rainfall, the end of the dry season has found these Peninsula reservoirs greatly depleted. As a result of this low stage the turbidity of the water at these times was greatly increased due to the inflowing water cutting through deposits of fine sediment, wave action on the sediment and the fact that the reduced volume of storage afforded shorter period of retention for sedimentation. Delivery of Hetch Hetchy water has made possible the filling of the reservoirs and provides assurance of maintaining the storage at near capacity, which will avoid in large measure the extreme turbidity previously occurring, and effect a material reduction in the chlorine requirements which were at an extremely high rate during periods of high turbidity.

There possibly has been some slight improvement in the quality of water delivered to consumers in San Francisco with respect to taste and odor, as is evidenced by the reduction in the number of bad water complaints, notwithstanding the fact that there have been innumerable shut-downs throughout the system due to extensive additions and changes of flow in our gridiron system during the past year. This, however, we are inclined to attribute more to the higher levels we have been able to maintain in our Peninsula storage reservoirs, enabling us to withdraw water at elevations offering the best quality of water.

Beyond these present benefits we have assurance for all time that the quality of the water at the source will not deteriorate, that with necessity, any contaminating influence of surface water will be eliminated by further diversion, and that with the increasing ratio of draft from Hetch Hetchy, improvement in quality of water delivered to San Francisco will progress continuously.

2. Chemical qualities

Hetch Hetchy water is extremely soft and of very low mineral content, samples from the reservoir show a mineral content of from 13 to 25 p.p.m. and a hardness of 5 to 12 p.p.m. On its way to Crystal Springs Reservoir additional mineral enters solution so that at Pulgas Outfall we find the mineral content increased to 140 p.p.m. and the hardness to about 30 p.p.m.

The mineral content and hardness of the local waters impounded in Crystal Springs Reservoir prior to delivery of Hetch Hetchy water varied over quite a wide range depending in large degree upon the seasonal runoff into the reservoir and the amount of contribution from other local sources of supply, such as the Pleasanton Wells, Sunol filter beds and Calaveras Reservoir. In October of 1934 just prior to delivery of Hetch Hetchy water, water in Crystal Springs (with 3,350 million gallons impounded) showed a mineral content of 252 p.p.m. and hardness of 182, San Andres which derives its supply partly from Crystal Springs and partly from direct runoff showed mineral content 228 and hardness 149. At the present date (May 18) with about 15 billion gallons impounded the mineral content is 115 p.p.m. and hardness about 80 p.p.m.

Representative mineral analyses at various points of the system are shown in table 1.

In a general way, the columns from 1 to 5 show the progressive change in the chemical content of the water as it moves from the Mountain source to the Peninsula storage system which provides, in the main, the water distributed in San Francisco. Column 6 gives the analysis of the water in Crystal Springs Reservoir as made just prior to delivery of Hetch Hetchy water, which took place October 28, 1934.

TABLE 1

Analyses of water at various points—Hetch Hetchy System

Mineral content in parts per million

	HETCH HETCHY RESERVOIR 1	MOCCASIN RESERVOIR 2	IRVINGTON PORTAL 3	PULGAS OUTFALL 4	CRYSTAL SPRINGS 5	CRYSTAL SPRINGS PRIOR TO HETCH HETCHY 6
Silica and insoluble	3.1	3.8	5.3	4.6	3.9	6.4
Sodium	1.6	2.3	32	12	8	24
Calcium	1.6	1.2	2.5	16	17	46
Magnesium	0.35	0.52	0.68	3.3	4.4	16
Iron	0.13	0.12	0.18	0.10	0.17	0.2
Aluminum	1.0	0.28	0.29	1.1	2.6	0.3
Bicarbonate	4.9	8.6	43	54	76	164
Sulphate	2.5	2.2	26	29	17	38
Chloride	2	2	13	8	10	22
Alkalinity	4	7	35	48	62	135
Total solids	25	22	108	141	102	252
Hardness	12	7	12	30	74	182
pH	6.9	7.1	7.6	8.3	7.3	7.9
Turbidity	1−	1−	1	1	2	4
Temperature	70°	57°	61°	54°	52°	61°
Date	8/8/35	8/8/35	8/6/35	12/6/35	1/9/36	10/17/34

The hardness of water is perhaps the most common index for comparing waters as to the chemical quality as affecting its use in the household and industry. It is probably fair to assume that water delivered to San Francisco in the future will have an average hardness of not more than 80 p.p.m. as compared with 180 p.p.m. prior to delivery of Hetch Hetchy water. Whipple in his book the *Value of Pure Water* as a basis for comparing the relative value of waters of different degrees of hardness, placed a penalty on the harder water equivalent to 10 cents per million gallons for each part per million difference in hardness. On the basis of our present consumption of 55 million gallons daily this would amount to some $200,000 per year. On the basis of studies made more recently by Hudson & Buswell (*Journal*, June, 1932), this reduction in hardness would effect an annual soap saving of approximately 80 cents per capita or $560,000 per year.

3. Quantity

The completion of the Hetch Hetchy Aqueduct and delivery of water from this source into our Peninsula system forever laid the spectre of a "water famine" which had arisen from time to time in seasons of scant rainfall to confront the people of San Francisco and to give the officials of the old Company and those who succeeded to their responsibility the keenest anxiety and on several occasions to force definite and drastic action to augment the water supply. We need only to go back to 1930, the year the City acquired the system. Entering the dry period in May, with storage of 16,475 million gallons, it was apparent that in the event of a succeeding season of subnormal rainfall there was possibility of absolute depletion of the supply in the following year. As an immediate relief measure the Department put down some 17 wells and constructed the necessary pumping plant and developed some 6 m.g.d. in San Francisco, and at the same time steps were taken to secure the necessary legislation and appropriation of funds to bring in a supplementary supply from the San Joaquin River or from the East Bay Municipal Water District. In October an agreement was entered into with the District, surveys were made and 13 miles of right of way acquired by December 25 when construction of the connecting line was commenced. This line, which was 36 inches in diameter for about one-half of its length and 44 inches for the remainder, and the necessary pumping station, were put in service on February 22, 1931, 59 days after starting field work, at a cost of, approximately, $1,000,000.

During the period of its use, until January 12, 1932, a total delivery of 7 billion 880 million gallons was made—without which San Francisco's supply would have been absolutely exhausted September 1st of 1931. To be freed from this constant threat of a water shortage and to be assured of a supply adequate probably for all time is a benefit that can not be measured in monetary terms for it may be truly said that a community must pay whatever price that is necessary to secure a water supply adequate to meet its requirements. An abundant supply of water of good quality is essential to the industrial development and growth of a community, for such growth and development can not extend beyond the capacity of the supply to meet its requirements.

The Hetch Hetchy Project has been developed not only to provide for San Francisco's requirements but also with a view to meeting the needs of what may be designated as the South Bay Metropolitan area. This Metropolitan area broadly is considered to include in addition to the City and County of San Francisco, that portion of San Mateo County in the Bay drainage area, the Santa Clara Valley, and the southern portion of Alameda County.

Water productivity available to these areas, exclusive of the Hetch Hetchy supply, on the basis of studies made by Mr. M. J. Bartell in 1928 and 1930, was as follows:

	m.g.d.
San Francisco Water Department sources	54*
San Francisco private sources	12
San Mateo County Bay slope	10
Santa Clara Valley exclusive of irrigation	20
Southern Alameda County	8
	104

The Hetch Hetchy Project with the enlargement of the O'Shaughnessy Dam now under way has a developed capacity of 210 m.g.d., with future available storage developments the potential capacity of the Project is a safe yield of 400 m.g.d. which combined with the local supply provides a total in excess of 500 m.g.d.

On the basis of a recent population forecast for the region involved, which forecast was based on careful and exhaustive studies and a consideration of the per capita consumption of water in the various communities in this South Bay Metropolitan area, table 2 was developed by Mr. Bartell, in a report on the subject.

While it might appear presumptious to forecast a population growth for a period in excess of 160 years, this has been done with a full knowledge of the limitations on a basis that appears, perhaps, as reasonable as any that might be developed. In his studies, Mr. Bartell reached the conclusion that the population of the area involved will reach a fairly definite saturation point, which can be gaged with some fair degree of accuracy from the experience of older Metropolitan areas. The limit of the water requirements for the area can thus be established with possibly an equal degree of accuracy. The significant thing then is, that the combined capacity of the Hetch Hetchy system and the local supply is fairly commensurate with the ultimate requirement of this entire area and as the delivery of water can be coördinated to meet the requirements of growth we are little concerned as to whether or not the population curve is accurate as to the rate at which the population increase takes place.

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* Exclusive of Lake Merced and Sunset wells capacity 2½ and 6 m.g.d., respectively.

TABLE 2

Estimated future water requirements of San Francisco and South Bay region

(Million gallons daily)

YEAR	SAN FRANCISCO	SOUTH BAY AREA	TOTAL
1940	73	46	119
1950	83	62	145
1960	94	84	178
1970	106	106	212
1980	120	138	258
1990	137	170	307
2000	155	202	357
2020	180	255	435
2040	190	300	490
2060	200	300	500
2080	200	315	515
2100	200	315	515

4. Electric power supply

Incidental to the water supply, electric power has been developed at two points: Early Intake and Moccasin Creek. The plant at Early Intake with a capacity of 3000 KV-A, as previously mentioned, was originally built as a temporary plant to provide power for construction purposes. Under orders from the Power Administration during the War, surplus power was disposed of through the Pacific Gas & Electric Network, the plant has continued in service ever since on a commercial basis, bringing in during that period revenue in excess of $800,000 in addition to the value of the power supplied for construction purposes. The Moccasin Power Plant with installed capacity of 80,000 KV-A was completed and put into service August 14, 1925. The plant is designed to utilize the full continuous flow of

620 cubic feet per second (400 m.g.d.) delivering power on the basis of a 75 percent load factor. Actually, it has been able to operate on a continuous flow of somewhat in excess of that amount. Electric energy from this plant, in an attempt to meet certain requirements imposed under congressional act conveying certain privilege in the National domain, has been disposed of ever since under an agency agreement with the Pacific Gas & Electric Company.

The cost of constructing these plants has been borne by Hetch Hetchy bonds. They represent an investment chargeable to electrical development of, approximately, $26,000,000. The following from the Income Statement for the year 1934–35 is presented as typical of the financial benefits accruing to the City:

Moccasin Power Revenues		$2,211,951.72
Early Intake—Revenues		92,373.67
		$2,304,325.39
Other Revenues, rents, interest		38,890.12
Total Revenue		$2,243,215.51
Operating Expenses	$362,303.09	
Allowance for Depreciation	175,000.00	
Bond Interest	691,294.50	1,228,597.59
Net Profit		$1,114,617.92

For the entire period since commencement of the Moccasin Plant, we have, similarly:

Gross Revenues	$21,876,864.43
Expenses, including Depreciation, Interest, etc	13,535,958.58
Net Profit	$8,340,905.85

Besides the Moccasin and Early Intake plants, there are a number of other power developments which may be made. Plans provide for the future installation of two additional units at Moccasin so that this plant may operate at full continuous flow on a 50 percent load factor,—other plants for which preliminary studies have been made include:

	KV-A
Red Mountain Bar capacity	15,000
Early Intake future capacity	42,000
North Mountain	24,000
	81,000

In addition to these, there are several other possible sites in connection with proposed reservoirs which will, ultimately, have to be developed.

5. Operating benefits

Water from Hetch Hetchy and Eleanor Reservoirs is delivered to Crystal Springs Reservoir, (flood elevation 288) and thence through connecting pipes to the University Mound Reservoir in San Francisco (elevation 172) entirely by gravity. From this latter reservoir 40 percent of the water used in San Francisco is distributed to consumers without pumping. Freeman, in his report on the Hetch Hetchy Project, by capitalizing the pumping costs, placed the value of gravity delivery of the water supply at these elevations at $5,000,000 for 100 m.g.d. and $20,000,000 for the ultimate delivery of 400 m.g.d.

Construction of the Hetch Hetchy Aqueduct, specifically that portion between Alameda Creek and Crystal Springs Reservoir, has made possible certain operating economies in the delivery of local water from the Alameda sources, by eliminating the necessity of operating the Pulgas and Belmont booster pumping stations. Formerly, water released from Calaveras reservoir flowed down Alameda Creek to Sunol, from here together with water from the Sunol filter galleries and that pumped from the Pleasanton wells, it was transported through the Sunol Aqueduct to the Niles Reservoir (elevation 181) and from which point part was delivered through the Bay Crossing Pipe and the Pulgas Booster pumps, against an operating head of 140 to 207 feet, into Crystal Springs, and part was delivered through the old Alameda pipe line to the Belmont Pumps, which under an operating head of 260 to 325 feet boosted it to the University Mound Reservoir. A pipe line connecting the Calaveras reservoir outlet with the Hetch Hetchy Aqueduct at the Alameda Creek siphon, permits gravity delivery direct to Crystal Springs. A small electric station to be installed near Irvington will boost the small amount of water derived from the Pleasanton Wells and Sunol into the main Bay Crossing Pipe Line at that point. The savings effected by these changes approximate $93,000 annually.

The dependable increased supply from Hetch Hetchy may be credited with certain other economies: (1) By sustaining the water level in Crystal Springs at a higher elevation, which will now be possible, some $12,000 annual pumping charges will be saved, due to reduced pumping head in lifting water from Crystal Springs to San

Andres reservoir, from which reservoir gravity delivery is made to distributing reservoirs at higher levels in San Francisco; (2) it has permitted the discontinuance of the use of Lake Merced as a regular source of supply thereby effecting an annual saving of some $35,000 due to shutting down the Lake Merced pumps; (3) similarly, the Sunset Wells and pumping Station have been discontinued with a saving of $38,000 per year, the saving in both instances make due allowance for the added burden transferred to the Crystal Springs pumps for serving the higher elevations; (4) the continued heavy draft on the Pleasanton Wells had seriously lowered the water table in the Pleasanton Valley and under an agreement with land owners in that district, the City, as successor to the Spring Valley Company is obligated to pay the additional power charges involved in connection with the operating of these private wells, resulting from the lowered water table, temporary discontinuance of the draft from our Pleasanton Wells is rapidly restoring the water table which will effect estimated savings of some $16,000 for these power changes.

The total savings in all of these pumping operations and power charges is estimated at $194,000 per year.

While, as previously pointed out, the amount of copper sulphate per million gallons has been reduced, this will possibly be more than offset by the requirement for treating the large volume of water which will be maintained in local storage.

Similarly, any reduction in chlorine dosage required at Crystal Springs outlet will be more than offset, for some time at least, by the expense involved in the necessary chlorine treatment at Irvington and Tesla Portal.

6. *Indirect benefits*

Aside from those direct benefits which accrue from greater supply, the improved quality of the water and the operating economies, there are certain indirect benefits which will be referred to briefly.

The storage development of 388,000 acre feet on the Tuolumne watershed, a tributary of the San Joaquin River contributes to the regulation and flood control of that river, helping to maintain the low water flow in the dry-river period and flattening out the flood peaks, all of which directly benefit the farmer and riparian owners, who in turn contribute to the support of the industries and business of San Francisco.

Under provisions of the Raker Act the City was required to construct and maintain certain roads and trails in the vicinity of the Hetch Hetchy Valley, for the benefit of the general public, making accessible to them portions of this wonderfully scenic country. At Mather, about nine miles from Hetch Hetchy Reservoir, the City has developed a summer recreational camp, where for a moderate charge a two-week's vacation may be spent with facilities for swimming, horseback riding, fishing and other similar activities. Here, also, is provided an auto camp where the tourist may stay over night or spend a day or two at nominal charge. Sanitary sewage disposal is provided for at these camps to avoid possible contamination of the water supply.

The employment provided in the construction of this Project, involving the expenditure of over $85,000,000 for labor and materials, has contributed in no small degree to the prosperity of the small towns in the vicinity of the work, and to the manufacturers and dealers in materials, equipment and supplies, in San Francisco and elsewhere.

Mention must also be made of the inestimable value of the favorable advertising which San Francisco has enjoyed as the result of the great interest which not only the engineering profession but the public generally has taken in the several elements of the Project and the progress of the work. During the construction period, innumerable excursions of civic bodies and fraternal organizations were conducted over the work, besides a regular bus service for tourists which was operated from Yosemite Valley to the Hetch Hetchy Dam during each summer season. Records kept show that during the past four years more than 80,000 people visited the O'Shaughnessy Dam, over 50 percent of whom were from outside of San Francisco. The volume of publicity which was given to the completion of the Project in the newspapers throughout the United States was in excess 10,000 column-inches,—all of which must inevitably redound to the great benefit of the City in attracting population and industry.

SUMMARY

Summarizing the foregoing, we may list the benefits which have accrued from the construction of the Hetch Hetchy Project, briefly, as follows:

1. San Francisco has secured a source of water supply of the highest

sanitary standard and which will maintain that standard in perpetuity.

2. The water is of excellent chemical quality with mineral content of 13–25 p.p.m. and hardness of 12 p.p.m. The dilution of the local supply with increasing volume of this mountain water is greatly improving the chemical qualities of the water delivered to consumers. The hardness has been reduced from, approximately, 180 to 80 p.p.m.

3. The question of adequacy of water supply has been solved for all time to come. The 400 m.g.d. available supply is sufficient not only for San Francisco's ultimate needs, but also for that of the entire South Bay Metropolitan area.

4. San Francisco has acquired an electric power supply of 80,000 KV-A producing a present revenue of, approximately, $2,000,000 per year, with further potential developments which will more than double this capacity.

5. Direct operating benefits due to elimination of pumping stations representing actual savings of, approximately, $194,000 per year.

6. Various indirect benefits have accrued resulting from: Contribution to flood control of the San Joaquin; the opening of roads and trails and recreational facilities in the Hetch Hetchy region; the added employment and increased business incidental to the construction of the Project; the favorable advertising which the Project has directed to the City of San Francisco.

DISCUSSION

F. E. DeMartini (*Water Purification Engineer, Water Department, San Francisco, Calif.*): The paper presented by Mr. Eckart is a very thorough and interesting report of the Hetch Hetchy project and its benefits to San Francisco and the South Bay Metropolitan area. In the history of the development of the project, and of the dealings and decisions of the governmental agencies that had jurisdiction in the matter, Mr. Eckart has given a very clear picture of the many obstacles which had to be overcome to realize the acquisition of this water supply for San Francisco.

It has been pointed out that the Hetch Hetchy water is of excellent quality bacterially, physically and chemically, at its source. In its 142-mile trip to Crystal Springs Reservoir, it is subject to changes in character due to various factors, chief of which are: entry of water from Moccasin Creek into Moccasin Reservoir; entry of tunnel drainage water, principally in the Coast Range tunnels, and finally mixture with the local waters of the Peninsula Reservoirs.

The flow from Moccasin Creek may have turbidities of several hundred parts per million during storms, and more often than not three to five 10-cc. tubes are positive for the B. Coli Group. Mr. Eckart has explained that this flow from Moccasin Creek will be eliminated by a diversion dam in the creek and pipe line under Moccasin Reservoir. Infiltration water in the Coast Range tunnels is highly mineralized, but is diluted so much by the tunnel supply that it has no serious effect, in fact, it raises the alkalinity, calcium content, and pH to more favorable values with respect to the corrosion tendencies of the water. The crenothrix introduced with this tunnel infiltration has been a problem, but has not caused serious impairment in quality. Chloramine treatment has been found to control it successfully.

The mixture with the local waters increases the hardness, but even so the hardness averages only 80 p.p.m. in Crystal Springs Reservoir and this will probably be reduced, as a greater proportion of the Hetch Hetchy water enters the local reservoirs. A possible advantage due to the mixture with local water may be the increase in iodine content of the water served to the consumers. It is questionable, however, if the Hetch Hetchy water is as low in iodine as some expect. A half dozen analyses on samples below Moccasin Reservoir indicate an iodine content of 1.5 p.p.b. which compares favorably with most of the local supplies ranging from 1.0 to 3.0 p.p.b. Laboratory studies are being conducted, using a simplified procedure, with a view to learning more about the iodine content of both the Hetch Hetchy, and the local supplies.

Mr. Eckart has pointed out, and it should be emphasized, that the local supplies in San Mateo and Alameda Counties are of excellent quality bacterially and chemically. Algae growths and turbidities (at times of low reservoir levels, as in the past) have caused difficulties. By permitting higher lake levels at all times, the Hetch Hetchy supply reduces turbidity. During the past year, copper sulphate treatments were fewer than usual. It is perhaps too soon to draw definite conclusions on the net effect of Hetch Hetchy water on algae growths.

The provision of an abundant supply will permit thorough flushing of the distribution system. This program will do more to eliminate complaints of bad water than any other factor. The water purification division investigates certain types of complaints which are not explained by obvious causes. However, except for an occasional unusual problem, most of these complaints may be traced to deposits, growths, or disturbances within the mains. Flushing within the district affected is of temporary benefit only, but a carefully planned program for the entire city should be of great help.

Prior to the delivery of Hetch Hetchy water to Crystal Springs Reservoir, laboratory control was carried on by the Water Department, to a limited extent. The problems resulting from the introduction of this new water supply have necessitated studies and laboratory control that have led to expansion of the purification division. There is no question about the value of this work and inasmuch as the Hetch Hetchy project has contributed to the development of this sanitary consciousness laboratory control may be counted in part, at least, as a benefit accruing from the Hetch Hetchy project.